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JAMES R. RANDOLPH, Editor

The JOURNAL OF THE AMERICAN ROCKET SOCIETY is devoted to the purpose of disseminating information on the development of the rocket and jet propulsion. This is accomplished by printing original technical papers on jet propulsion, data on the latest experimental developments, historical notes, patent specifications, reviews of books and current literature, and news of the Society and individual members.

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LIFESAVING ROCKET

(In this Coast Guard test a 3.25-in. Navy rocket hurled a seven-foot steel stake 1171 feet, trailing a $^1/_4$-in. steel cable, which is paying out from the reels in front of the launcher. The cable is strong enough to carry a breeches buoy from a stranded ship to the shore, but it wasn't strong enough to pull the stake out of the ground. Another rocket, with a shorter stake, is shown at the left. Use of rockets for livesaving purpose at sea and on shore is discussed by Wadsworth W. Mount.) See pages 5 to 8.

JOURNAL OF THE AMERICAN ROCKET SOCIETY

Number 73 James R. Randolph, *Editor* March, 1948

Pushbutton Space Travel

On another page of this issue we publish an account of an airplane which took itself off from an American airport, flew itself across the Atlantic, and landed itself at an English airport, without the guidance of human hands. This development has come about because of the disastrous consequences of human fallibility and the slowness of the human mind when dealing with anything as fast as an airplane.

The same incentive applies to the development of automatic controls for space travel. A satellite ship can go around the world in as little as eighty minutes. At seven miles a second it takes less than half a minute to go from outer space into air so dense that meteors are turned white-hot by its resistance to their passage. When things begin to happen to a space ship they will happen even faster than they do in a plane!

A rocket which can take itself off, travel in its perdetermined orbit, and land itself on the moon or Mars will be a very expensive thing to develop. But once developed it can be made in any desired quantity. It can be very much smaller than a man-carrying rocket, and that means a lot when we are still expecting to need more than a hundred tons of rocket to land one ton on Mars. Even when carrying passengers, automatic control eliminates the need for the pilot's skill, and will enable a large expedition to be scattered among many small rockets, removing the risk of losing them all through one collision with a meteor.

Within the past year the Signal Corps was successful in obtaining a radar reflection from the moon. Now they are talking confidently of trying for a radar reflection from Mars. The fact that such a project is being seriously considered indicates that short-wave radio communication and television between the earth and Mars would be possible today if we had suitable equipment on both planets.

Hence it seems likely that the first trip between the worlds will be a robot rocket, which will land automatically on the neighbor world, and will radio back instrument readings and television, showing what that world is really like and whether or not it is suitable for human beings.

We Need Hobbies

The untimely death of Dr. Goddard may be a warning to other rocket enthusiasts that success, long delayed, can be fatal when it comes. We

dreamed of success when we were young, and our dreams are still young dreams. Now when we see them coming true we forget that our hearts and bodies are no longer young—that they cannot stand the pace of young dreams coming true.

It we are to live long we must learn to take delayed success casually, as a part of the day's work. And we can best do this if we partly divert our enthusiasm to new interests and new dreams. Each of us needs a hobby to which he can give a part of the enthusiasm he formerly gave to rockets. This new interest will lessen the intensity of our interest in rockets, yet the dreams it arouses will be dreams to fit our years. They will not kill us in the coming true.

Rockets for the Woods

The bazooka won its spurs in the deserts of North Africa, where its back blast merely added more dust to an atmosphere already very dusty from the action of other weapons. But anyone who has ever used it or seen it fired has dreaded the necessity of using it in forests or brush lands that are dry and likely to catch fire. In a later issue we hope to be able to describe in more detail the work being done by one of our directors, Edward F. Chandler, toward a solution of this problem.

Mr. Chandler's basic idea is to have the rocket start as some other kind of projectile, and not become a rocket until it is far enough away to keep its back blast from doing serious damage. His launcher looks something like a flare pistol, and functions much as a flare pistol does. The rocket contains a delay-action fuse, which is adjusted as the result of experiment to the most satisfactory time interval.

Of course such a rocket does not have the recoillessness of the bazooka, and for this reason it cannot be made as large. Yet it can be larger than a rifle grenade, with a greater range, and it can be appreciably larger than a gun or mortar projectile with the same recoil limitations. A practical way to start the design is to give as much recoil as the shoulder or mounting can stand, decide how slow the muzzle velocity can be without causing excessive droop of the trajectory before the rocket action starts, and from the combination of these two factors decide how heavy the projectile can be. It then rests with the designer to distribute this weight between rocket power to give range and speed, and explosives to give destructive power on arrival. The hollow-charge principle can be used here, the same as in the bazooka, to increase the destructive power of a low-velocity projectile, and reduce the need for a high velocity.

The dust of the bazooka, and even the fires it starts, can be excused in a large-scale action. It is in the small actions where both are taking cover from the air that the Chandler rockets will make the greatest difference. Yet such actions are often decisive when small forces are scattered over a wide terrain.

U. S. NAVY 3.25-IN. ROCKET MOTOR SET TO FIRE 50-LB STAKE-GROUND-ANCHOR PROJECTILE FROM LAUNCHER TOWING 1/4-IN. STEEL CABLE

ROCKET MOTORS PROJECT HEAVY STEEL CABLES

By Wadsworth W. Mount

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A WAR-BORN invention which may find important peacetime uses in lifesaving and fire fighting is the Mount-Intertype Cable Dispensing Reel, which makes possible the firing of steel cable so that it pays out cleanly from a relatively small container. Using simply constructed projectile heads, which are designed to attach to the lead-end threads of standard U. S. Navy rocket motors of 1.25-in. diameter up to 3.25-in. diameter, it has been found that almost any range can be obtained with steel cables up to one quarter of an inch in diameter. These reels of steel cable and their corresponding projectile assemblies are manufactured by Intertype Corporation of Brooklyn, N. Y., who developed them in collaboration with the author.

In a recent official demonstration for the U. S. Coast Guard, a maximum

Presented at a meeting of the American Rocket Society, Engineering Societies Building, New York, N. Y.

range of 1171 ft was obtained using various 3.25-in. Navy rocket motors and Mount-Intertype reels, each reel wound with 825 ft of $^1/_4$-in. steel cable of 7000-lb breaking strength. In order to have sufficient cable on this shot, the bitter end of the first reel to be fired was fastened to the leading end of a second reel, a means by which any length of cable may be obtained without making the individual-reel packages too heavy to handle readily. Eight hundred and twenty-five feet of this $^1/_4$-in. cable weighs over 90 lb. The projectile fired on this test was a Mount-Intertype stake-ground-anchor assembly, weighing 65 lb, including the Navy rocket motor attached, which is designed to act as its name implies. On that test it buried itself so securely in the ground that it took two men heaving on a crowbar to remove it, thus indicating a powerful forward anchorage for the projected cable.

Use in Rescue Work Studied

Tests are under way to determine the advisability of using these reels with their 825 ft of $^1/_4$-in. cable, or other sizes and lengths, to enable one ship to pass a heavy towing hawser to a disabled vessel in heavy weather by firing a strong enough line on the first shot. This would replace the present method by which a light line is fired across first and then heavier and stronger lines are pulled across until the hawser itself is pulled over, all of which often keeps the vessels pitching close together for a dangerously long period of time.

Consideration is also being given to the desirability of equipping ships with these reels of steel cable, Navy rocket motors, and self-anchoring projectiles for use in case the ship goes ashore at a point where no shore station can send help. With storm winds blowing shoreward, any shot line would be more likely to reach further if shot from ship to shore than if fired upwind from shore to ship using identical equipment. Once the stranded vessel had fired its cable and obtained an anchor on shore by means of the stake-ground-anchor assembly, the inboard end of the cable could be fastened at a high point on the ship. If at least one member of the crew in a life jacket could be slid down this line, as on a trolley, and get ashore, he could permanently secure the shore end of the line and thereafter assist in hauling other people ashore on, or with the aid of this first-shot line. Such a rig

ARRANGEMENT AND PACKAGING OF STEEL CABLE

STAKE-PROJECTILE ANCHORS $^1/_4$-IN. STEEL CABLE 433 YD AWAY; 3.25-IN. ROCKET MOTOR SHOWN BROKEN OUT OF ADAPTER

STAKE ANCHOR BEING REMOVED FROM SAND

might have helped save some of the 40 men of the crew and 8 Coast Guardsmen who went out to help the stranded tanker that foundered on the rocks 300 yards off the coast of Wales in the spring storms of 1947 with the loss of all 48 men.

Standard rocket motors fired electrically make possible such simple and light apparatus for firing cables that such equipment might find uses in saving firemen and others trapped above the blaze of burning buildings. It could also be used in construction work where ravines have to be bridged and for reaching lines to the tops of tall trees in lumbering operations. Throwing lines of rope is an ancient practice, but successfully projecting steel cable, which weighs about one third that of equivalent-strength rope and packs in about one fourth the space required for an equivalent length and strength of rope, is new.

This equipment was originally designed to fire steel cable vertically in the path of enemy planes attacking at low level, as in the Pearl Harbor attack, and to be fired by remote control so that this defensive means would always be alerted. In the first official tactical demonstration at Eglin Field in 1943, steel cables of $^3/_{32}$-in. and $^1/_4$-in. diameters were cleanly projected vertically by a projectile fired from a shortened 37-mm mortar barrel. The Mount-Intertype reel was first demonstrated officially at the Aberdeen Proving Ground in the latter part of 1942 and information on its ability to pay out its cable cleanly when fired either vertically or horizontally had been forwarded to all branches of our Armed Services. Subsequently these reels and projectiles were designed to fit standard Army

60-mm and 81-mm mortars with the reels carrying from 500 to 1250 ft of $^1/_8$-in. diameter cable of 2000-lb breaking strength for roughly equivalent ranges. It was soon found however that standard Navy rocket motors provided the most effective and flexible means of propelling the cable-throwing projectiles and their trailing lines and gave anchorages strong enough to cause the cables to break before the anchors pulled out on ranges of up to a quarter of a mile carrying $^1/_8$-in. and $^1/_4$-in. cables.

Reels have been delivered carrying 800 feet of $^5/_{16}$-in. diameter cable whose breaking strength is listed at 9800 lb and reels have been designed to carry a half mile of $^3/_8$-in. diameter wire rope whose strength is 14,400 lb. The principle of the reel on which American and foreign patents have been issued appears to be applicable to any size of steel or rope line that it is desired to project. There are rocket motors now in existence able to carry projectiles weighing from 5 to 500 lb.

If it ever again becomes necessary for us to provide our shores or strategic points like bridges, airport runways, etc., with some sort of a defense against sudden air-borne attack, driving in at low altitude to avoid radar detection, it might again be necessary to consider the possibility of having these points protected by rocket-fired projectiles pulling heavy steel cables vertically into the path of the attackers. The effect is to destroy the enemy's initial aim and give our forces a little more time to man their more mobile defenses. One-quarter-inch steel cable is believed to be larger than any balloon-barrage cable used, and when fired up only 500 ft, it offers an obstruction to planes at the hundred-foot level for approximately six seconds of flight. On the official tests at Eglin Field, Fla., this weapon scored seven technical hits out of seven tries.

TYPOGRAPHICAL ERRORS

GEORGE P. Sutton's paper, as published in the December, 1947, issue of this JOURNAL, contained several typographical errors. These errors are obvious to anyone familiar with the subject but are nevertheless embarrassing. They were the result of the publishing setup we had then, and which has since been changed.

The first equation on page 2, the first page of Mr. Sutton's article, should read:

$$V = \sqrt{\frac{2gkR}{k-1}\frac{T}{M}\left[1-\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right]}$$

The fourth and fifth equations should read:

$$K_n = \frac{(n_C)^c(n_D)^d}{(n_A)^a(n_B)^b} \qquad K_p = \frac{(p_C)^c(p_D)^d}{(p_A)^a(p_B)^b}$$

PRESENT AND FUTURE OF ROCKETS

By Dan A. Kimball

Member ARS, Vice-President, Aerojet Engineering Corporation, Azusa, Calif.

DAN A. KIMBALL

TWO years after cessation of active hostilities, it is appropriate to review the status of rocket-development work. With the war-production emphasis removed, it is evident that the progress of the rocket industry must hinge on the importance assigned to military preparedness. Commercial and scientific applications will grow in magnitude, but the conclusion appears inescapable that these activities cannot offer adequate support for the needed basic development. This condition might be considered typical of war-born industries which later find important and self-sustaining peacetime applications.

Two principal centers of rocket development on the West Coast are the Aerojet Engineering Corporation and the Jet Propulsion Laboratory of the California Institute of Technology. Both organizations trace their origin to a small pioneer group which started work in 1939 under the guidance of Dr. Theodor von Kármán. This project, supported by the Army Air Force, was known as GALCIT No. 1 (Guggenheim Aeronautical Laboratory, California Institute of Technology).

In 1942, the Aerojet Engineering Corporation was organized to produce rocket motors developed by GALCIT. Since 1945, Aerojet has been a subsidiary of the General Tire and Rubber Company. The company is fortunate in retaining two of the GALCIT group: Dr. von Kármán and Dr. Fritz Zwicky, the latter being director of research at Aerojet.

Evolution of the JATO Motor

The history of the 12AS-1000 JATO (jet assisted take-off) motor, now being produced in large quantities by Aerojet for the Bureau of Aeronautics, U. S. Navy, began with GALCIT Project No. 1 in 1939, when experimentation was initiated on both liquid- and solid-propellant rockets. The first solid-propellant charge was a pressed powder called GALCIT 27, and the first application of this propellant was to a small motor delivering 28-lb

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thrust for 12 seconds. This motor was fabricated from tubing with the charge cast in place.

About this time assisted take-off of aircraft by rockets began to appear feasible. In August, 1941, six of these motors were attached to an Ercoupe light plane and several take-offs made successfully at March Field, Calif. These tests demonstrated the practicability of auxiliary jet propulsion as applied to aircraft.

The next solid motor delivered 200-lb thrust for 8 seconds, and used a potassium perchlorate-asphalt propellant mixture selected after considerable research had demonstrated its improved storage properties and performance. This design consisted of a seamless-steel tubing chamber closed on the forward end by a welded plate. A cap, threaded to the aft end, carried the nozzle, igniter, and safety assembly. The chamber was first lined with a restricting material which consisted essentially of the fuel used in the oxidizer-fuel combination which comprised the propellant. The propellant was then mixed at a temperature of approximately 300 F (so that the asphalt was liquid) and the material, which had a consistency approximating that of bread dough, was cast into the chamber. After cooling, the surface of the material was reamed smooth and flat, and the head assembled to the motor.

During the development of this motor, work was also proceeding on liquid-propellant rockets. This work culminated in a serviceable design, a 1000-lb thrust motor for application to the A-20 airplane. Aerojet's first job in 1942 was the production of the AL-1000 liquid-propellant motors, but in January, 1943, the production of 500 Model 8AS-200 solid-propellant motors was begun. These motors were, with few exceptions, identical to the GALCIT No. 1 design. The propellant, GALCIT 53, was used in its original form.

Success in the production of these small motors led to the development of larger thrust motors. The first step was taken in the development of an 8AS-500 motor (500-lb thrust for 8 seconds duration). The distinguishing feature of the design of this motor was the central nozzle surrounded by the igniter assembly and a number of blowout disks. The charge was cast into the chamber. Only a few of these motors were produced, because before the order was completed, experience resulting from the use of JATO motors dictated that units of 1000-lb thrust should be developed.

The first 1000-lb motor design was built, again, around seamless-steel tubing. In the case of this motor the joint problem was solved by the use of standard flush-joint oil-well tool thread, patented by the Hydril Corporation of Los Angeles. This thread is a two-step square-tooth form with a taper seal. The nozzle was again mounted on the center line of the unit, but the igniter and safety assembly were shifted to one side. This motor was also loaded by lining the chamber with restriction material and casting the

propellant into the chamber. It was rated for a duration of 5 seconds. Tests were carried out in the summer of 1943 and the first production 1000-lb thrust solid-motor order was placed by the Navy for delivery in late 1943. This order called for 2000 two-piece 8AS-1000 motors. Also to be furnished were 50 12AS-1000 and 50 10AS-1000 motors for experimental purposes.

Meanwhile, a pilot plant for the mixing, loading, and assembly of solid-propellant motors was under construction at Azusa, Calif. Refinements had been made in the propellant formula, and the restricting liner had been improved.

An all-out effort was made in which the Aerojet office force, after their day-shift at Pasadena, drove to Azusa and worked evening shift at the propellant plant. The motors were delivered on time.

Through all of this development, the temperature range of safe operation had been a problem. At low temperatures the difference in thermal-expansion coefficients of the charge and the chamber wall led to cracks between charge and liner which exposed more area to burning with an attendant rise in pressure. Also the charge, like any asphalt, became brittle at low temperatures and sometimes would break up from the shock of the igniter. At high temperatures the charge would flow when the motor was placed on its side, opening additional area to burning. These conditions led to "blows" of the safety diaphragm and in some cases of the chamber itself.

In order to solve these difficulties and read a safe operating temperature range of 0 to 130 F, modifications in both the charge formulation and the method of supporting it within the chamber were proposed. Modifications in the propellant aimed toward a more plastic charge at low temperatures while maintaining physical strength at high temperatures. The cartridge unit was proposed as the solution for holding the charge within the chamber. In the cartridge, bonding of the liner to a material whose coefficient of thermal expansion differed from that of the charge was to be avoided. The charge was to be completed outside the chamber, where better inspection was possible, and inserted into the chamber later.

A development program was set up to pursue these objectives, and in early 1945 the cartridge unit, using ALT-39 propellant, was placed in production.

Further development was necessary, however, both in the propellant formulation and in the charge design. This development resulted in the ALT-161 formulation which is the one being manufactured today. The charge design has been simplified by taping an aluminum plug into the forward end of the charge and supporting the charge from a stud which is buried in the aluminum plug and attached to the forward cap with a nut. The corrugated cardboard wrap is replaced with a metal sheath which has a lip crimped over the aft face of the charge. This sheath restrains the propellant from

slipping at high temperatures and provides better support for the charge during storage. It is secured to the cartridge with metal banding material.

The two-piece cartridge motor in its present form represents a high stage of refinement in the production of an asphalt-base propellant charge. Routine production tests are made over the range from −10 to 140 F with excellent results. Over this temperature range the charge will withstand short-time accelerations of 12 g in any direction and several days' storage in a horizontal position, although for indefinite storage it must be in a vertical position.

Credit for the continued reproduction of this performance goes to the Aerojet Process Control Department, which keeps a watchful eye on the propellant charge from the time the raw materials enter the plant until the finished motor is loaded into the pallet for shipment Each ingredient in the propellant is carefully tested for conformance to specification before mixing begins. Components of the fuel compound are weighed on card-punching scales and the compound tested before mixing with the oxidizer begins. Again weights are recorded and a continuous watt-meter record is taken during the mixing process to check mixing conditions. Supplementary controls on the quality of the mix include determination of the viscosity of the completed mix. Careful control of the cooling of the castings is maintained to insure elimination of internal strains. Assembly of the cartridge is checked at every step of the process, and the liner and tape materials are closely controlled.

Production motors are currently tested under a statistical-sampling plan. A lot is selected from production flow and may be composed of a minimum of 48 units or a maximum of 210. The number of units in each lot may be composed of as many batches as production flow permits. In the testing of a lot of 48 units, for example, 7 units are selected at random to be tested at −10 F and 5 units at 140 F. If all units fire properly according to thrust and duration limitations, the lot is accepted by the Navy.

If by chance one unit selected on this plan fails to come up to specification the entire lot is withdrawn. This sampling plan compels the manufacturer to keep all production phases under extremely close inspection in order to minimize rejections.

A task originally concerned with the development and testing of a few experimental rockets of unpredictable performance had, at the end of the war, achieved a production capacity of 1000 per day, and a performance record of such reliability and predictability as to compare more than favorably with any other power plant ever developed. Today the Aerojet JATO motor not only is accepted in all United States and many foreign military circles, but it has been approved by the Civil Aeronautics Administration for use on passenger-carrying airlines. CAA Engine Type Certificate No. 249 has been issued on the current model, 14AS-1000 D4.

Currently, the application of resin-base propellants to the standard 14AS-

1000 motor is being developed. Through the superior physical properties of this propellant it is expected that the safe operating-temperature range will be extended and that indefinite storage in a horizontal position will be possible. This will facilitate permanent installations on aircraft for emergency use.

Experience gained in the development of the 14AS-1000 motor is now being incorporated in the design of a 14-sec duration 250-lb thrust motor familiarly called the Junior JATO. This motor is being applied to light aircraft. It weighs about 50 lb and is approximately 7 in. in diameter and 20 in. long. The Junior JATO (14AS-250) also has CAA Engine Type Certificate No. 250. This motor is capable of operation without change of nozzle aperture from −40 to 140 F.

On the horizon lies the smokeless JATO motor. Preliminary experiments on propellant formulation are under way. As research toward the ideal propellant continues, the design of metal parts will proceed toward the goals of more efficient function, lighter weight, and lower cost so that JATO, born of war, may be of the most possible use in peace.

Booster Rockets

Rocket motors in the booster category have to date been all of the solid-propellant class, if one excludes liquid JATO from the booster category. The booster rocket is employed in general to deliver high acceleration to pilotless aircraft for periods of time not exceeding 4 seconds. Such rockets employing a castable resin-base propellant have been built at Aerojet with thrusts ranging from 2000 to 100,000 lb

Problems associated with this development include the control of physical properties of the cast propellant and the reduction of chamber weight.

Uniformity of the propellant is satisfactory from the mixing point of view but the casting and curing operation is not entirely free of internal-stress problems. Several methods of examination and nondestructive testing are being investigated. In view of the high acceleration loads, it has been decided to avoid long slender propellant configurations by using multiple short castings.

The conventional form of propellant "grain" for high-thrust short-duration rockets has been a hollow cylinder which burns on inner and outer surfaces thereby maintaining constant thrust because of constant total burning area. This configuration exposes the chamber wall to hot gases thus requiring a heavier design to provide the necessary stength. New geometric designs, such as the "rod and tube" and a star-perforated grain, will keep the chamber wall insulated from hot gases and also produce constant thrust.

Other items stressed in current development programs are the attainment of a smokeless solid propellant and the reduction of temperature sensitivity.

Liquid-Propellant Rockets

Most of the Aerojet experience in the liquid-propellant field has been concerned with the nitric-acid-aniline system. This combination has the advantages of self-ignition, high density, and freedom from the boil-off problem in storage. Units under design range from 1000-lb thrust to approximately V-2 scale.

The monopropellant nitromethane has received a considerable amount of attention at Aerojet. This propellant has good logistic properties as well as fairly high density. The pure compound nitromethane is subject to detonation at temperatures above 550 F, but additives are under investigation which will extend the safe operating range.

Small-scale studies are being conducted to establish motor-design parameters for these propellant systems. Principal items of investigation are cooling, geometric design, injection of propellants, and optimum chamber pressures. Certain applications in view may require emphasis on the problem of continuous variation of thrust.

Components and Accessories

Rocket engines which are to be supplied with liquid propellants for fairly long operating periods (in excess of 10 to 30 seconds, depending upon thrust) can be built for less weight with turbopump systems rather than pressurizing gas. The gas turbines for this purpose have been supplied by gas generators resembling rocket-combustion chambers, and when the conventional propellants are used, a coolant fluid is added to protect the turbine wheel. An alternative system as employed in the V-2 is the relatively low-temperature gas generation offered by the decomposition of hydrogen peroxide. Where operating times can be fixed, solid propellants may be employed for gas generation.

Other applications for light compact gas turbines powered by rocket propellants present themselves frequently. Among these applications are turbojet starters and electric generators.

Rocket Test Facilities

The experience gained by Aerojet personnel during five years of pioneering has led to contracts for design and construction of test facilities in Southern California; for the Navy Bureau of Aeronautics at Point Mugu, and for the Air Matériel Command at Muroc. In this connection the General Electric Company co-operated with Aerojet in making the first application of television to the observation of rocket firing at Azusa in November, 1947.

Design problems associated with rocket-test facilities range from heavy construction to precise instrumentation. The "pits" in which rocket engines are operated must be separated from inhabited areas by extremely heavy walls. The explosive potentialities of stored propellants must be

considered in the location and installation of tankage. Instruments which are to record the engine performance must have the nearly contradictory properties of great sensitivity and resistance to heat and shock.

For the static testing of assembled rocket vehicles complex structures are required. If the rockets must be tested in a flame-downward position the provision of excavations and flame diverters becomes an additional problem.

The solution of these facility problems is proceeding with the aid of some German information, some engineering analysis, and a limited amount of small-scale experimentation.

Future of the Rocket Industry

Although the commercial applications of rocket power are being developed to the fullest extent, it is evident that the industry at its present stage would be capable of only the barest subsistence without the support of military developments. It is unnecessary to debate the importance of continued and amplified support by the Armed Services.

The development of the V-2 by the Germans is one of the greatest engineering feats of all time in connection with military equipment and can be compared only with development of microwave radar and the atomic bomb by this country. The many sciences and new engineering techniques which were of necessity employed to make this weapon possible must define its successful operation as an impressive accomplishment, certainly possible only by the expenditure of very great amounts of money and human effort. Yet today there are several guided-missile programs under way in the United States which far surpass the V-2 in magnitude. No components of these supermissiles are at present completely developed and the requirements in the fields of aerodynamics, propulsion, and guidance are little short of fantastic.

It is quite conceivable that the next few years will see all large-scale gunnery give way to rocket projectiles and missiles. The "guns" which do remain may be in the nature of cylinder catapults powered by rocket propellants. The development of new fuels, particularly water-reactive chemicals, presents an unlimited field of possibility for the propulsion of Naval craft and weapons.

One of the repetitive features of history appears to be the development and prompt abandonment of rocket techniques after each war. One is astonished at the rocket weapons reported centuries back, but one is even more astonished at the failure of those civilizations to promote or even preserve their developments during periods of peace.

It seems entirely compatible with the requirements of National Preparedness that special emphasis be given scientific and exploratory ventures which make use of the same type of rockets employed in long-range weapons. Vehicles which will be powered to attain or approach the gravi-

tational escape velocity have possibly more immediate military significance than scientific application; certainly their commercial significance is far in the future. It is another historical fact that war-born technical developments have found commercial applications which perhaps would not otherwise have become apparent, or, if they had been visualized, might not have won the support required for development.

A novel approach to the classification and study of propulsive systems has been proposed by Dr. Zwicky in a paper called "Morphology and Nomenclature of Jet Engines."[1] A systematic examination is made of the possible "classes" of jet engines, as to mechanical properties, nature of propellants, use or nonuse of ambient medium (air, water, earth) in the propulsive reaction, etc. By this means one may uncover "gaps in the array of existing power plants" and be guided toward "invention and construction" of new engines. A by-product of the morphological approach is a concise and logical system of names for propulsive engines of various classes, for example: aeroduct, aeroresonater, hydroduct, hydroresonater. The first two are more commonly known as the ramjet and pulsejet, respectively. This approach has already proved effective. New propulsive systems, which cannot be described here because of security, are under development which owe their existence to this type of orderly thought, or "systematic invention."

The magnitude of the problems involved and the complicated and costly facilities required for much of the research in this field make it unlikely that commercial concerns will be able in the predictable future to support a significant portion of the necessary research programs with their own funds.

It will therefore be necessary for Service Agencies to obtain appropriations sufficient to support vigorous research or we will be faced with the certainty that other nations will surpass us in technological development. It is believed that basic research should be conducted both by commercial concerns and by educational institutions. Although the latter organizations are often well supplied with necessary personnel and (to some extent) facilities, the close day-by-day contact which commercial concerns maintain with development, production, and use makes them constantly aware of the gaps in present knowledge and adds incentive to their efforts to fill these gaps. Industrial organizations not only have shown themselves capable of effiicent and effective research direction, but they are inherently better adapted to making emergency shifts into full-scale production than are the educational institutions.

The progress of rocket development in the coming years will depend on continued teamwork by industry, educational institutions, and government agencies.

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[1] Published in the *Aeronautical Engineering Review* and in *Aviation*, June, 1947.

THE ACID-ANILINE ROCKET ENGINE

By W. P. Berggren,[1] C. C. Ross,[2] R. B. Young[3] and C. E. Hawk[4]

The importance of the density of rocket propellants is illustrated by comparing the size and range of certain rocket-powered vehicles in which nitric acid and liquid oxygen, respectively, are the oxidizers. Design and operation of the rocket engine is discussed, with emphasis on components other than the combustion chamber.

Nomenclature

The following nomenclature is used in this paper:

c = gI_{sp} = effective exhaust velocity, ft per sec
F = thrust, lb
g = acceleration of gravity, ft per (sec)^2
I_d = sI_{sp} = density impulse, sec
I_{sp} = $F/\dot{w}$ = specific impulse, sec
p_c = chamber pressure, psia
R = range, miles
s = specific gravity of propellant combination
W = propellant weight (total), lb
$\dot{w}$ = propellant flow rate, lb per sec

ROCKETS are distinguished from other jet-propulsion devices by their independence of atmospheric oxygen. A rocket power plant carries both oxidizer and fuel; these materials are known as propellants. Single compounds (such as hydrogen peroxide and nitromethane) which decompose in exothermic reactions are known as monopropellants. In the case of solid propellants the oxidizer and fuel are mixed in advance. The adjective "hypergolic," which is of German origin, has been applied to self-igniting propellant combinations. RFNA[5]-aniline and RFNA-furfuryl alcohol are hypergolic propellant systems.

The effectiveness of rocket propellant systems in the production of thrust is measured by the specific impulse, I_{sp}, which is the thrust in pounds divided by the total propellant flow rate in pounds per second. Specific impulse, accordingly, has units of seconds, and when multiplied by the acceleration of gravity it becomes the effective exhaust velocity of the rocket.

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[5] "Red fuming" nitric acid, containing 6 to 14 per cent NO_2.

$$I_{sp} = \frac{F}{\dot{w}} \quad [1]$$

$$c = gI_{sp} \quad [2]$$

Theoretical performance figures on common propellant systems, for 300-psi chamber pressure at sea level,[6] are given in Table 1.

TABLE 1 THEORETICAL SPECIFIC IMPULSE, EFFECTIVE EXHAUST VELOCITY, AND COMBINED SPECIFIC GRAVITY (for P_c = 300 psi at sea level)

	Oxygen-gasoline	RFNA-aniline	Hydrogen peroxide
I_{sp} (sec)	242	221	146
c (ft per sec)	7790	7110	4700
Spec. grav.	0.98	1.39	1.14

Extensive studies have been made to select chemical combinations whose properties warrant experimental investigation for rocket applications (7, 8).[7] The systems which look most promising from a theoretical standpoint invariably have high reaction temperatures (above 4000 F); also they often present severe logistic problems.

For fairly well-developed propellant combinations such as those listed in Table 1, typical experimental performance figures run between 85 and 90 per cent of theoretical specific impulse.

Density Advantage of the Acid-Aniline System

In addition to its self-igniting property with aniline and furfuryl alcohol, nitric acid is about 40 per cent more dense than liquid oxygen. Hence where tank volume is a significant item, the ten per cent advantage of the oxygen system in specific impulse is offset by the reduced structural weight and reduced vehicle size offered by acid-aniline. Density effect is most prominent when the rocket-propelled vehicle satisfies the following conditions:

1 Size and weight of the vehicle are determined mainly by the propellant tanks.

2 The major expenditure of impulse is against drag forces rather than inertia forces.

3 Total drag is influenced only to a small degree by adjustment of wings for lift and maneuvering.

For a specific calculation, rocket vehicles powered by RFNA-aniline at mixture ratio[8] 3 and by liquid oxygen and gasoline at mixture ratio 2.5 will

[6] Thrust of rockets increases with altitude, due to the reduction of back-pressure on the nozzle. Vacuum thrust will exceed sea-level thrust by about 15 per cent.

[7] Numbers in parentheses refer to similarly numbered references in bibliography at end of paper.

[8] Mass ratio, oxidizer to fuel.

be compared. The combined specific gravities of these propellant systems are respectively 1.39 and 0.98. For the example, the following additional conditions have been assumed:

4 The propellant load, in the case of oxygen-gasoline, amounts to $^2/_3$ of the gross weight. For acid-aniline the fraction becomes $^3/_4$, assuming a fixed ratio of propellant volume to total volume.
5 The propellants are expended entirely to overcome drag, in level flight at Mach number 1.5
6 The comparisons are made for three distinct situations:
   (a) A vehicle of given dimensions is fully loaded, first with the light (oxygen-gasoline) propellant combination and second, with the same total volume of the heavy (acid-aniline) combination. Range is compared for the two cases.
   (b) The gross weight is considered fixed. Range comparison is made for two geometrically similar vehicles carrying the respective propellant combinations, the over-all sizes being determined in accordance with assumption 4.
   (c) The required range is fixed. The size and weight required for the two propellant combinations are compared. Again, over-all geometric similarity is assumed.

Calculations will be carried out in accordance with (a), (b) and (c) of the preceding statement.

The range comparison for equal volumes would be given directly by the product[9] of specific impulse and specific gravity for each propellant system, except that a 5 per cent increase in drag has been assumed because of wing adjustment to carry the heavier propellants. This assumption is believed to be conservative because of the relatively small wings and low angles of attack used in supersonic flight. Accordingly, the rocket motor would be designed for 5 per cent greater thrust in the case of acid-aniline propulsion to maintain the same speed.

Where impulse is expended exclusively in overcoming drag at constant speed, the required thrust is equal to the drag of the vehicle at rated speed. It follows that the range is directly proportional to the total weight of propellants and to the specific impulse, inversely proportional to the required thrust. To compare two propellant systems:

$$\frac{R_2}{R_1} = \frac{W_2}{W_1} \cdot \frac{(I_{sp})_2}{(I_{sp})_1} \cdot \frac{F_1}{F_2} \qquad [3]$$

Substituting into Equation [3] for the case of equal propellant volumes, one obtains

$$\frac{R_2}{R_1} = \frac{1.39}{0.98} \cdot \frac{221}{242} \cdot \frac{1}{1.05} = 1.24$$

[9] This product is known as I_d, density impulse.

Conclusion:

(*a*) For fixed volume acid-aniline has a 24 per cent range advantage over liquid oxygen-gasoline.

Application of Equation [3] to the case of vehicles of equal gross[10] weight, and to the case of equal yields the following results:

(*b*) For a given gross weight, the acid-aniline system has an 11 per cent range advantage, and requires 21 per cent less volume.

(*c*) For a given range, the acid-aniline system permits a 35 per cent reduction in volume and an 18 per cent reduction in gross weight.

Care should be taken to associate these conclusions with the assumed conditions, which define the class of rocket vehicle to which they apply.

Components of the Rocket Engine

All accessible details of current design of liquid-propellant motors (combustion chamber, injectors, and cooling system) have been discussed in previous papers (3, 4, 5, 6). Other components of the rocket engine are the propellant feed system, valves, and controls.

The two principal methods of feeding in the propellants are: (*a*) Pressurizing, by means of a high-pressure supply of inert gas; (*b*) pumping, by means of high-speed centrifugal pumps driven by a gas turbine (gases for which are produced by rocket propellants). The latter system was used by the Germans in the V-2 missile and in the ME-163 airplane. This type of rocket engine is known in this country as the turborocket.

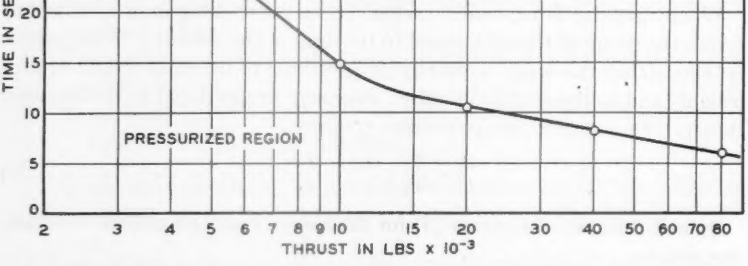

FIG. 1 CHANGE-OVER LINE BETWEEN PRESSURIZING AND PUMPING PLANT REGION IN TERMS OF THRUST AND TIME OF OPERATION

[10] In accordance with condition 4, this means one eighth more propellant weight in the case of acid-aniline.

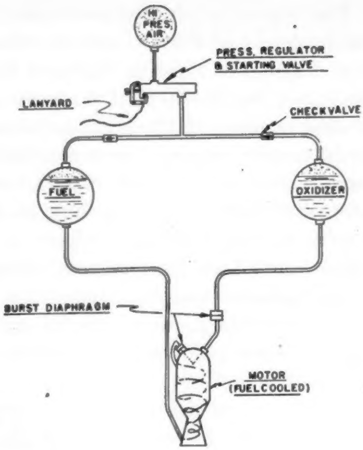

FIG. 2 ONE-SHOT OPERATING SYSTEM

The choice between pressurizing and pumping is chiefly influenced by weight, and in a secondary manner, by the additional complexity and cost of the turbopump system. For long duration, the turborocket has a definite advantage over the pressurized rocket. Fig. 1 shows the "changeover" line between the two systems in terms of thrust and time of operation, on a weight basis alone.

Pressurized Systems: For gas-feed engines the propellant tanks must withstand pressures of 450–500 psi. For longer durations these tanks become large weight items, as does the gas-storage vessel. However, the system possesses the great advantage of simplicity.

There are two general types of gas-feed engines in use today: The so-called "one-shot" system used in expendable, noncontrolled vehicles; and the "intermittent operation" system used in controlled vehicles and JATO[11] units. The one-shot system is the simplest of rocket engines consisting of only the basic elements. A schematic diagram is given in Fig. 2. The components are: (*a*) rocket motor; (*b*) propellant-line burst diaphragms; (*c*) filters; (*d*) propellant tanks; (*e*) gas storage or pressure tank; (*f*) pressure regulator and reducing valve; (*g*) starting mechanism; and (*h*) pressure-line check valves. In a typical acid-aniline engine the motor is regeneratively fuel-cooled and operates at 300-psi chamber pressure. The required propellant tank pressures are 425–450 psi, and the initial storage-tank pressure is 3000–2000 psi. The high-pressure gas from the pressure tank is reduced and maintained at the feed pressure by the regulator. The engine is started by mechanically releasing the regulator shutoff trip which allows gas to flow to the propellant tanks. As the pressure rises in the tanks, the diaphragms in the propellant lines at the forward (injector) end of the motor rupture at approximately 100 psi allowing the propellants to flow through the injector into the combustion chamber. Ignition occurs spontaneously as the propellants come together and the motor comes up to thrust in less than one second. Once started, the engine cannot be stopped until either or both propellants are exhausted or propellant flow to the motor is stopped by detonating a line. The system may be reoperated by replacing the burst diaphragms, rearming the regulator, and recharging the propellant and pressure tanks.

[11] Jet-assisted take-off.

The type of gas-feed engine which until recently had received the most emphasis as a JATO application is the repeated-operation type, a schematic flow diagram of which is shown in Fig. 3. This is similar to the one-shot system of Fig. 2, except that a valve called the "propellant control valve" is used in place of the propellant-line diaphragms. This valve, which is hydraulically operated, acts as a shutoff and starting control valve. The rocket motor may be started and stopped at will by opening and closing the propellant control valve so long as the propellant tanks are pressurized. The motor will come up to thrust in approximately 1.5 sec and stop (zero thrust) in 0.5 sec from valve actuation.

Intermittent operation imposes a severe requirement upon the rocket motor since the cooling jacket is upstream of the propellant control valve and the inner (combustion chamber) wall is subjected to the full feed pres-

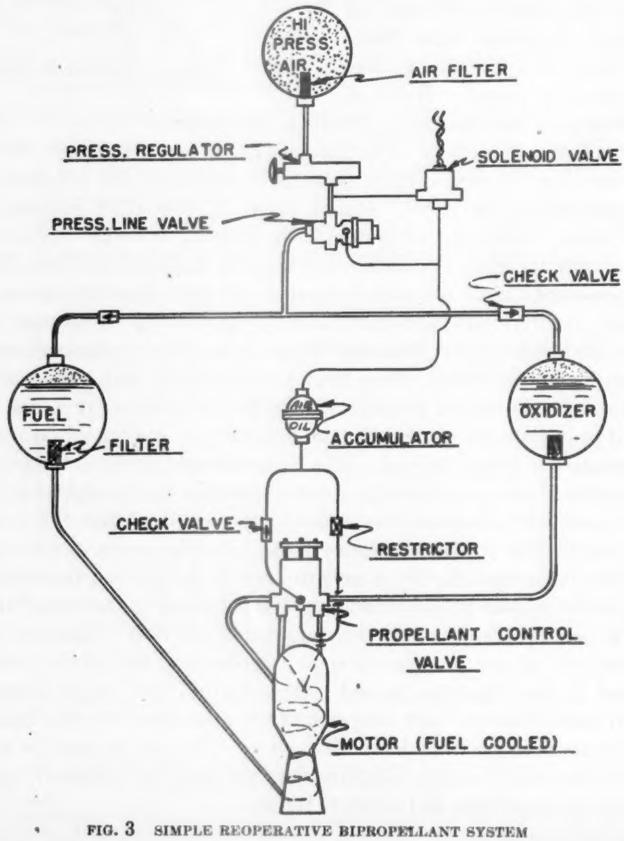

FIG. 3 SIMPLE REOPERATIVE BIPROPELLANT SYSTEM

sure in the hot condition. This condition makes special strengthening design features necessary to prevent the wall from collapsing. The motor performance is the same as that of the one-shot motor.

The Turborocket: When the propellants are fed by a turbopump system the tanks need be pressurized only to a slight degree to prevent cavitation in the pumps. The pump-suction-head requirement is one limitation on design speed of the turbopump system. Subject to this limitation and that of stress the speed should be as high as possible for light weight and compactness.

In general single-stage centrifugal pumps are used; the gas turbine being mounted between the oxidizer pump and fuel pump all on a common shaft. The turbine gas is derived from a chemical reaction which may be the decomposition of hydrogen peroxide into steam and oxygen or the burning of the main-motor propellants in a suitable chamber. In the former case the products of decomposition can be used directly in the turbine since the gas temperature is on the order of 900–1100 F. In the latter case the combustion gases must be diluted with water or an excess of the oxidizer so that the temperature is reduced to a safe figure, not more than 1500 F. In the case of the acid-aniline system water with antifreeze is the diluent. A schematic diagram of the chemical-turbine system with auxiliary gas source is shown in Fig. 4.

The thrust of the engine is varied by controlling the output of the gas generator and hence the propellant-pump-discharge pressures and flows. Chemical-turbine systems whether auxiliary or self-feed are relatively simple and reliable. The turbine consumes approximately one to two per cent of the total propellant flow which amounts to 25–30 lb per bhp-hr. Turbine wheels are usually of the impulse type either single-stage, two-stage, as on the V-2, or re-entry as on the Walter unit of the ME-163 interceptor.

The German V-2 rocket engine is a typical auxiliary chemical-turbine type. The gas-generation system is entirely separate consisting of hydrogen-peroxide tank, catalyst tank, high-pressure-nitrogen tanks, pressure regulator, hydrogen-peroxide and catalyst-control valves, and decomposition chamber.

Other Feed Systems: When the rocket engine is employed as a supplementary power plant such as a JATO application there is a possibility of using air from the compressor (of a turbojet) or exhaust gases (from a reciprocating engine) to operate the turbopump system. This method has the disadvantage of dependency on operation of the nonrocket power plant.

Valves and Controls

One of the most vital phases of liquid-propellant rocket-power-plant development has been that of valves and controls. The very physical and chemical properties which are desirable for satisfactory rocket-propellant

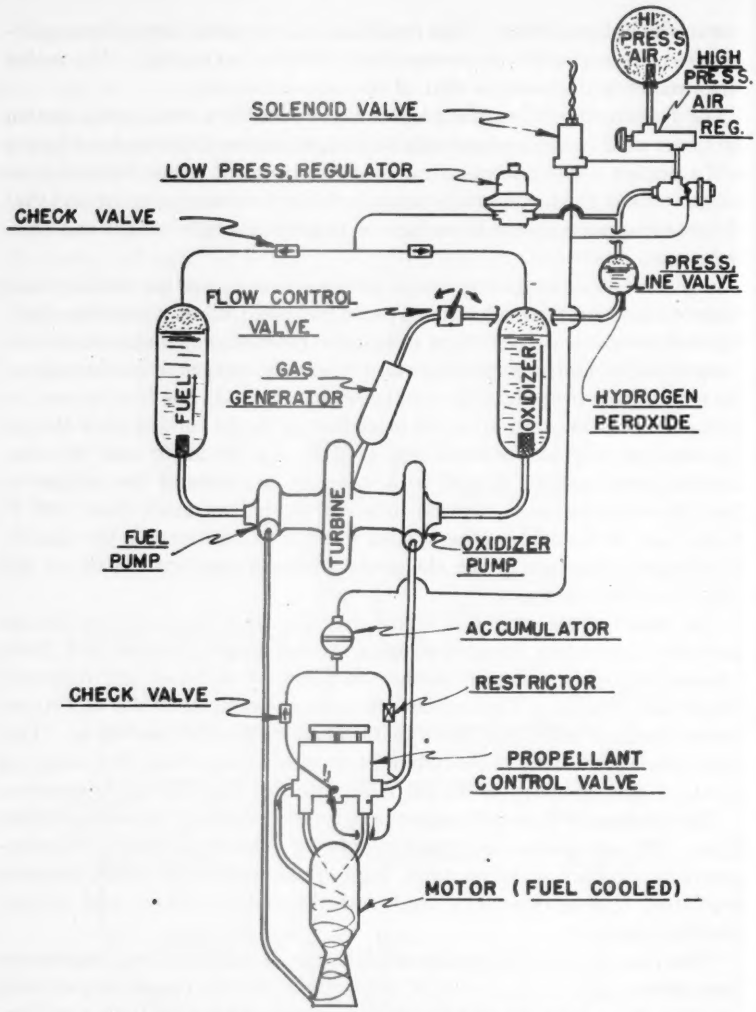

FIG. 4 CHEMICAL-TURBINE SYSTEM WITH AUXILIARY GAS SOURCE

operation are usually the opposite properties from those which would be selected on the basis of ease of handling and safety.

In the system shown in Fig. 3 the basic control requirements are (*a*) starting means, (*b*) propellant-tank-pressure regulation, and (*c*) control of propellants entering motor during the starting and operating periods. The system is started by electrically energizing the solenoid valve which simultaneously pressurizes the pilot line serving the pressure-line valve.

In the majority of present rocket units the solenoid valve is used mainly for pilot operation. When used in this way one standard-size low-capacity valve is readily adaptable to control systems having a wide range of thrust or propellant flow. Unless the minimum weight in any given system is demanded it is not usually economical to design direct-operating solenoid valves in large sizes. In most cases the solenoid valve can be similar to, or identical with, components normally used in standard-aircraft hydraulic-systems. The only special requirement desired in such valves is low leakage when handling high-pressure air.

Presssure Regula'or: To maintain a constant propellant-tank pressure or feed-pressure regulation, it is necessary to use a regulator valve which maintains a constant outlet pressure as the air-tank pressure falls from an initial high value to some intermediate value during the run. The maintenance of constant feed pressure will give constant propellant flow, and consequently, constant thrust over the duration of firing.

Fig. 5 illustrates the variation of air-tank pressure and regulator pressure versus time for a typical firing. The regulator-pressure-time curve is idealized as a straight line. In practice, however most regulator valves are subject to regulator-pressure variation as the inlet pressure varies over the range normally encountered in efficient pressurized-rocket systems (i.e., over a range of at least 4 to 1).

Normally, there are two ways to prevent large regulator-pressure variations, namely: (*a*) Making a regulator valve with an exceedingly large operating diaphragm or piston area and using very long springs having low-spring constants; and (*b*) using two-stage regulators so that the pressure variation is divided in such a manner that the second-stage regulator is subjected to only a minor inlet-pressure variation.

The Aerojet regulator design for which no cross section is shown due to the restricted nature of the device overcomes regulator-pressure variation by means of a special-compensating feature. To keep down size and weight and to simplify the design, this regulator utilizes a compensating piston attached to the valve shaft which is located in the inlet chamber. This compensating piston has a slightly unbalanced area with reference to the orifice seat. Because of this unbalanced area as the valve lifts during normal operation, the force on the unbalanced area is proportional to the loss in spring load. If the regulator shaft was balanced so that it was unaffected by inlet-pressure variation, the outlet or regulator pressure would still fall off. This fall-off in regulator pressure is almost entirely due to the loss in spring load from the original setting. The fall-off in

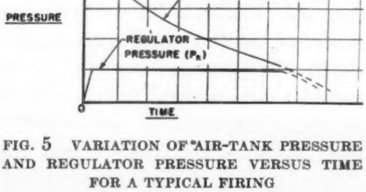

FIG. 5 VARIATION OF AIR-TANK PRESSURE AND REGULATOR PRESSURE VERSUS TIME FOR A TYPICAL FIRING

regulator pressure could be reduced a certain amount by making an abnormally long spring with a proportionately low spring constant. However, by utilizing the fall-off in inlet pressure to balance the variation in spring load, an approximately flat regulator-pressure characteristic is maintained.

Check Valve: In order to prevent the mixing of fumes some means must be used to separate the common air lines between the propellant tanks. This is usually accomplished in a reoperative system by use of check valves. Most check valves used in liquid-propellant-rocket units are of similar design to standard AN hydraulic equipment. The poppet and swing-check-valve designs are both used with some degreee of success. For test-pit installation, check valves have not been mandatory; but for units which must be moved, boosted, and stored while loaded with propellants, check valves must be used. The high vapor pressure of acid-type oxidizers may cause a seepage of acid fumes into the air lines. During the starting period these acid fumes may be forced into the fuel tank, thus causing a minor explosion. In most cases the amount of acid fumes is not dangerous but the fact that they contact the fuel sometimes causes the formation of a sludge which clogs the filters.

The major problem associated with check-valve design has been that of obtaining 100 per cent checking action. This problem has led to the design of various types of valves having special plastic seats for zero gas leakage, and the utilization of stainless-steel seats, bodies, springs, and components in order to prevent seizure because of galvanic or chemical corrosion. The poppet-type check valve is one of the most difficult valves to lubricate, because of the fact that the high-velocity air flow quickly dries out or removes most lubricants. Also, the poppet-type valve has guide surfaces and consequently close clearances which tend to pick up any particles of dirt or sludge which may flow through the valve. For this reason only carefully designed and tested poppet check valves can be incorporated in a liquid-propellant system which requires reoperative service for extended periods of time.

The swing-check-type valve has several advantages over the poppet type; namely, its freedom from binding or seizure (due to deposits of impurities) and the exceptionally low-pressure loss through the valve. However, one big disadvantage has been the fact that the materials normally used for achieving zero leakage must be rubberlike and have noncold-flow physical properties. These properties are not compatible with the plastics currently available for use with many of the strong-oxidizer propellants. A second and more or less resulting disadvantage is the fact that the swing-check-valve design is usually not able to stand large back pressures. For installations involving high acceleration the swing-check valve is difficult for successful application. As a result, the poppet-check valve is now used on most systems requiring rugged check-valve duty.

In certain systems the use of two pilot-operated pressure-line valves has

eliminated the need for check valves. This scheme usually has given slightly more dependability but at an increase in weight, cost, complexity, and space requirements. In most instances the added dependability is offset largely by the factors which have been noted.

Propellant-Control Valve: The function of the propellant-control valve is to act as an on-and-off valve and to provide means for controlling the flow of propellants entering the combustion chamber during the starting phase of operation. In all rocket motors firing horizontally any large accumulation of propellants in the combustion chamber is liable to cause a severe explosion. This is then the main reason why the propellant-control valve must control the initial flow during the starting period. Fig. 6 indicates the degree of throttling or the pressure loss required across a typical propellant-control valve in order to bring up the thrust smoothly. Fig. 7 indicates the variation in propellant flow and thrust versus valve motion and time in a typical installation. Fig. 8 indicates a diagrammatic sketch of a typical bipropellant control valve.

Although various bipropellant combinations have differences in starting characteristics the general control problems remain approximately the same, that is: (*a*) The initial flow must fill the downstream line and injector volumes and both propellants enter the motor at approximately the same time; (*b*) the throttled flow must be maintained during the time required for the propellants to mix and ignite; and (*c*) after ignition the flow of propellants should be brought up to rated flow as fast as the conditions of safety in control tolerances and structural loadings will permit.

In order that the propellant-control valve may be opened at a relatively uniform and controlled rate some suitable means must be provided to throttle the actuating fluid. In most units the actuating fluid is a liquid such as the fuel or standard AN hydraulic oil. Use of a liquid in the actuating system is necessitated because of the erratic and abrupt operation normally associated with pneumatic cylinders. Fig. 3 indi-

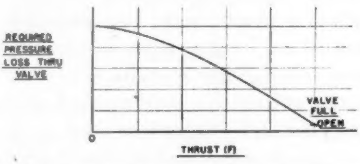

FIG. 6 PRESSURE LOSS REQUIRED ACROSS TYPICAL PROPELLANT-CONTROL VALVE TO BRING UP THRUST SMOOTHLY

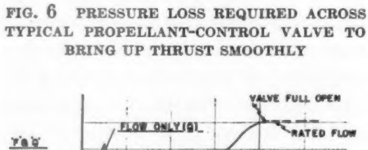

FIG. 7 VARIATION IN PROPELLANT FLOW AND THRUST VERSUS VALVE MOTION AND TIME IN TYPICAL PROPELLANT-CONTROL VALVE INSTALLATION

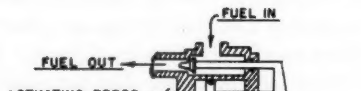

FIG. 8 DIAGRAMMATIC SKETCH OF TYPICAL BIPROPELLANT-CONTROL VALVE

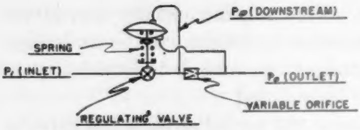

FIG. 9 DIAGRAMMATIC SKETCH OF FLOW-CONTROL VALVE

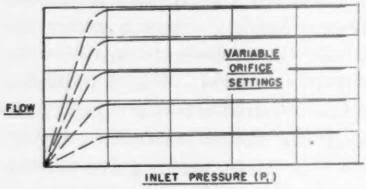

FIG. 10 EFFECT OF VARIATION OF INLET PRESSURE ON FLOW CHARACTERISTICS OF TYPICAL FLOW-CONTROL VALVE

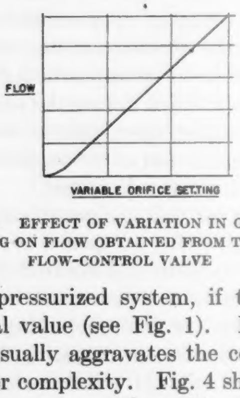

FIG. 11 EFFECT OF VARIATION IN ORIFICE SETTING ON FLOW OBTAINED FROM TYPICAL FLOW-CONTROL VALVE

cates a common system of propellant-valve actuation in which a small closed hydraulic system is used. The so-called accumulator contains a reservoir of hydraulic oil separated from the air line by a rubber diaphragm. When the pilot-line actuating air pushes the hydraulic oil from the reservoir it passes through a restrictor, which may be adjusted to give a certain time delay, and thence to the propellant valve actuating cylinder. To obtain a faster reduction of thrust when the system is shut off, the hydraulic oil is returned through a check valve to the accumulator as the propellant valve closes. A typical shutdown time is on the order of less than 0.5 sec.

Controls for the Turborocket

When the propellants are fed into the combustion chamber by turbine-driven pumps, the rocket power plant can be installed with less weight than a comparable pressurized system, if the duration or impulse exceeds a certain critical value (see Fig. 1). However, the switch to a turborocket system usually aggravates the control problems and results in a system of greater complexity. Fig. 4 shows one of the simplest bipropellant turborocket systems. The turbine is driven by a hydrogen-peroxide combustion pot and the system has the following advantages: (*a*) It is relatively stable, since the power input to the turbine is controlled by the flow-control valve; (*b*) the flow-control valve may be used for thrust variation during either the starting or operational phases; and (*c*) the turbine may be started by initiating the flow of hydrogen peroxide into the combustion pot. All components of this system are identical, or at least reasonably similar to those previously discussed, except for the flow-control valve.

Flow-Control Valve: The flow-control valve is a pressure regulator which maintains a constant-pressure differential across a variable orifice. Fig. 9 shows a diagrammatic sketch of the valve. In most designs the variable orifice is a narrow slot which has practically a constant rate of area increase or decrease with rotation. The rectangular slot also has a nearly constant

coefficient of discharge so that the variation of flow is linearly proportional to orifice area over quite a wide range. Fig. 10 and Fig. 11 are typical curves showing the effects of variation of inlet pressures and orifice setting on the controlled flow.

There are many variations of the turborocket system described in Fig. 4. Some systems incorporate combustion pots or gas generators which use the same propellants as are used in the main rocket motor. These systems usually require control of a fuel, oxidizer, and diluent (or coolant) entering the combustion pot. It has been common practice to utilize separate flow-control valves for each propellant.

As long as any of the above systems utilize a pressurized feed to the combustion-pot propellants there is little danger of instability. The only stability requirement is usually an overspeed control to protect the turbine-pump assembly from disintegration in the event that a propellant line in the high-pressure system should break. The resultant loss in pressure head in the propellant line would probably cause a destructive overspeed condition unless the flow of the propellants entering the combustion pot were stopped. However, if the system is regenerative, because the combustion-pot propellant feed is taken off the discharge of the main propellant turbopumps, then a rise in pump-discharge pressure would tend to increase the flow of propellants to the combustion pot. The flow-control valves maintain constant flow for large variations in inlet pressure and they therefore stabilize the system.

Other Methods of Turbulent Control: In turborocket systems not using flow-control valves the input power from the combustion pot is balanced by the power taken from the turbine through the use of (*a*) automatic by-pass valves which increase the power absorbed by the pumps in relationship to the pump-discharge-head increase over a stable value, and (*b*) the use of a regulating-type valve which controls the amount of total propellant flow to the combustion pot in relation to the discharge pressure of either the fuel or oxidizer pumps.

The use of by-pass valves to stabilize the regenerative turborocket systems is complicated by the fact that they must handle large flows and that they are inherently unstable. To help stabilize the by-pass valves the use of dash pots and the elimination of dynamic effects (by designing the operating area so that it is large compared to the controlling orifice) may be resorted to. However, these steps increase size and weight and, in general, the use of by-pass valves presents a prohibitive weight penalty.

The use of by-pass valves in systems where high flows will be encountered is also unfavorable from the heat-dissipation standpoint. Continual power dissipation through the by-pass valves will heat up the propellants excessively even if they are returned to the main propellant tanks. If the duration is long enough the propellant temperature will exceed the critical value above which the pump suction characteristics are unfavorable.

Regulating valves have been designed which control the amount of propellant flow to the combustion pot in relation to the discharge pressure of the fuel pump. Need for further development of this system is indicated especially in designs where thrust variation is desired. Such a control scheme will give stability at any thrust value and will not call for the continual absorption of large amounts of power.

Conclusion

Nitric-acid propellant systems are about 10 per cent lower in specific impulse than liquid-oxygen systems, and the acid presents problems at welds and seals.

The 40 per cent greater density of a typical acid system, as compared with oxygen-gasoline system, more than overcomes the specific-impulse disadvantage in the case of a constant-speed winged-rocket vehicle. In this case the acid system has about 24 per cent greater range for the same external dimensions.

Other features of rocket-engine design are quite similar for acid or oxygen systems, except for the absence of an ignition problem in the case of RFNA with aniline and furfuryl alcohol in any proportions.

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7 "Some Possibilities for Rocket Propellants," by A. S. Leonard, JOURNAL AMERICAN ROCKET SOCIETY, no. 68, 1946, pp. 12–16; no. 70, 1947, pp. 20-31.

8 "Morphology and Nomenclature of Jet Engines," by F. Zwicky, *Aeronautical Engineering Review*, vol. 6, no. 6, 1947, pp. 20–23.

New Weapons Research

THE Government is spending hundreds of millions in preparation for possible war in the upper atmosphere, war involving supersonic speed, and war in Arctic cold, President Truman's scientific research board reported recently. Discussed in the report are studies for development of guided missiles, jet and rocket aircraft, atomic weapons, agents of poison and bacteriological warfare, and a host of electronic devices.

Ordnance, Jan.–Feb., 1948

METALLURGICAL ASPECTS IN THE DESIGN OF ROCKET MOTORS

By J. N. Nutt

Mem. ARS, Project Engineer, Reaction Motors, Inc., Dover, N. J.

THIS paper presents some metallurgical considerations and problems which face the metallurgist in the design of rocket motors. The engineers can sit down and dream of the simplest or most complicated rocket, but it is the metallurgist's job to provide the material which will transpose the ideas of the designer into the reality of the rocket. His problem is real. It does him no good to sit down and dream of what material he would like to use, and what properties these materials should have. He knows exactly what his tools are and that they are limited by nature itself to the elements, although he is aided by his fellow man's ingenuity in combining and alloying these elements to produce the various useful metals of his time. The skill of the metallurgist must be varied. He must understand the aim and the method of attack of the designer, and be able to choose the material on hand which will best be suited for all conditions to accomplish the desired results.

Rocket Metals Subjected to Extreme Conditions

As the metallurgist sees the rocket motor, he has many problems to consider. Temperature of operation and the corrosive action of fuels and gases are the most pertinent and serious. In every respect the conditions that the materials which make up a rocket motor are subjected to are extreme. No other power plant can compare with it. The temperatures, for one thing, which are experienced are at both ends of the scale from −300 F (almost absolute zero) to theoretical values in the neighborhood of 7000 F which as yet cannot even be measured. The corrosive action of fuels and hot gases at supersonic velocities are also extreme. These conditions restrict the choice of the metals which can be used. Besides these factors, the metals which can be formed, welded, and worked by usual fabrication methods, and those which are economically available are also important considerations. These metals must be strong enough to harness the enormous power which the rocket motors produce. Nowhere in engineering history have such complicated conditions been experienced in one unit.

In the early days of the development of rockets designers looked for a material which might withstand the high temperatures they expected to produce. No literature was available. No tests on any available metal for rocket conditions had been made. Designers built rockets, nevertheless, even though the rockets lasted only a few seconds before burning out. The next step was to make the design so as to keep the metal cool by some

means, for no metal alone could withstand the high temperatures. This resulted in the regeneratively cooled rocket motor.

Austenitic Stainless Steels

In present designs the austenitic stainless steels of the 18–8 type have proved themselves useful despite several limitations. The knowledge of handling 18–8 has been developed considerably in the past few years. Various types can be formed, welded, and machined by normal procedures after a certain amount of skill has been obtained. It is tricky, nevertheless, and unless handled properly, it may be troublesome. Some of its limitations are its relatively low strength, poor coefficient of heat transfer, and its susceptibility to intergranular corrosion under certain conditions. In the annealed condition, 18–8 has a tensile strength of 90,000 psi but its yield point on which most design and stress analyses are based is only 35,000 psi. This is actually lower than 24ST aluminum which has a yield point of 55,000 psi. The coefficient of heat transfer is only 0.04 cgs units (calories per sec per cm^2 per C per cm thickness), as compared to 0.93 for copper, or only $4^1/_2$ per cent as good in this respect. Contrary to common belief, stainless steels will rust. Particularly after welding, an unstabilized stainless steel may be susceptible to severe corrosive attack. The presence of chromium in solution is the medium which produces the corrosion resistance of this material. During welding the chromium tends to precipitate as carbides in the grain boundaries leaving the matrix near the grain boundaries void of chromium. Thus a low-alloy iron is left in these areas which rusts easily. To avoid this phenomenon certain stainless steels, types 321 and 347, have been developed whereby small additions of titanium and columbium have been added to stabilize the carbide formation. These metals are added because they have more of an affinity for carbon than the chromium and therefore keep the chromium in solution and prevent the formation of the chromium carbides. Because of the austenitic structure of 18–8 it does not respond to heat-treatment to improve its physical properties. It does, however, withstand relatively high temperatures without oxidizing, and can withstand the corrosive action of most of the present-day fuels.

Welding a Useful Technique

The art of welding has played an important part in the development of rocket engines. The designs have been toward lighter motors. Welded parts have been useful in advancing this trend. Where thin sections, odd shapes, close fits, and pressure-tight joints have to be provided, the use of welding has been invaluable. Many different types of welding have been used including gas welding, electric arc welding, atomic hydrogen welding, and inert-gas-shielded arc welding. Each has its own limitations, and must be understood and used properly where best suited. Stainless steel has fitted well because it responds readily to most of the various types of welding.

The problem of forming the various odd-shaped parts of rocket motors has brought about some new methods of production. The Solar Aircraft Company of California, for instance, has developed a patented process called the "Sol-a-Die process" for cold-forming queer-shaped parts. This method involves the use of a series of dies which gradually form a sheet into the desired shape. Each successive die gives the piece more of a bend than the previous one. This, it is claimed, results in forming pieces without effecting any loss in wall thickness of the metal. The ancient art of spinning is being considered in forming rocket motors, and much experimentation is being carried on in this field. Stainless steel again has been used successfully with both of these methods. Although it work-hardens fairly rapidly with cold work it may be annealed easily to eliminate work-hardness and to restore to original ductility without much loss in shape or springback.

High-Temperature Strength Data Needed

As far as future rocket metals are concerned, a great deal of research is needed to determine the strength characteristics at high temperatures of materials to be used on rocket motors. Hardly any data of this type have been obtained. In the gas-turbine field, extensive programs have been encouraged and sponsored to obtain data on the physical properties of materials under simulated turbojet-operating conditions. These data, although the nearest source, are not applicable to rocket conditions. The short-term high-temperature tests for gas turbines are in the neighborhood of 1000 F for several hundred hours' duration. These results are useless as far as rocket motors are concerned. The requirements of a rocket motor are much higher temperatures for much shorter periods of time.

The present need is for data on high-temperature short-time tests at several thousand degrees for one- or two-hour duration. Data of this nature would be invaluable. The gas-turbine man feels embarrassed when he records results of strength values for less than 100 hours on a new heat-resistant metal. But this may be very useful for the rocket where the time of operation is shorter. Tests of the kind that rocket metals need would demand some new equipment and techniques, but they would be very useful. This problem should be undertaken and pursued immediately. The rocket industry is no longer a week-end hobby, but is a major factor in the advancement of the country. Rocket motors are coming out in sizable production quantities today, but as yet the amount of data on the physical properties of the materials used under operating conditions is practically zero. This is a serious situation and should be rectified immediately.

Use of Ceramic Materials Promising

The materials which will be used in the design and fabrication of future rockets present some interesting thoughts. Ceramics and porous metals

seem to offer good possibilities. It is well known that some of the highest melting-point materials include alundum, zirconium, carbon, and silica, among others. Because of their present nature of brittleness and poor resistance to thermal shock, however, these ceramics will offer many problems before they can be considered practical. In order for them to become of value, these ceramics must be developed so that they will have not only resistance to high temperatures, but also fairly good thermal conductivity, strength, some ductility, and ability to resist spalling in the presence of the extremely hot, highly corrosive, and oxidizing atmospheres. Methods of forming and fabricating these materials will have to be developed before they can even be tested in rocket motors. The possibilities are there, however, and offer a challenge to the metallurgist.

The introduction of sweat-cooled motors creates another source of ingenuity for the metallurgist. Up to the present time all endeavors have been directed toward the production of solid strong materials which would resist the passage of gases and liquids. Sweat-cooling has just the opposite requirements. This method of cooling the walls of the rocket motor uses a porous metal which will allow gases and liquids to pass through it in sizable quantities and still maintain a semblance of strength and rigidity. The corrosive action of the fuels has to be considered as acting throughout the wall and not merely on the surface. The production of these porous metals must include maintenance of uniform shape, porosity, density, permeability, particle size, and purity. The entire sweat-cooling program is being held up now because the metallurgist has not had the opportunity or the time to foresee its advancement and therefore does not have the answers for its problems.

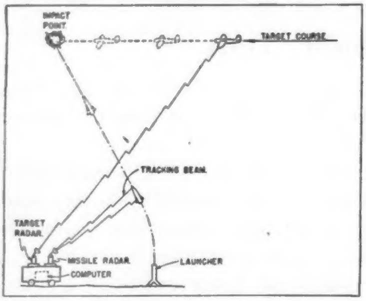
Lighter Rocket Motors Needed

Another aspect of future designs of rocket motors will be to endeavor to make them lighter. Weight is an extremely important consideration in the rocket motor whose prime purpose is to attain high altitudes. Each bit of unnecessary weight therefore is detrimental and objectionable. The most obvious answer is to use lighter-weight metals in the construction of the rocket, and thus replace some of the present high-density alloys by the lighter metals. Aluminum and magnesium are the only commercial materials which can be considered and these are almost wholly useless because of their poor corrosion resistance and low melting temperatures. Their lightness, however, makes them important and their adoption for rocket motors must be investigated.

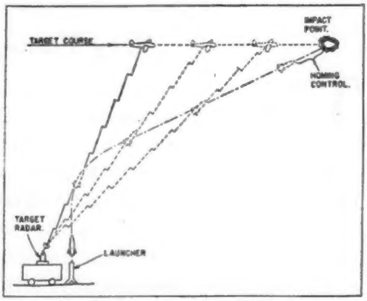
As the rocket industry advances, it brings with it many challenges to the metallurgist. Most of the work is entirely new and cannot be compared with past experience of the metallurgical field. The future of rockets depends upon the materials which can be developed and upon their correct application by the metallurgist.

TRENDS IN GUIDED MISSILES[1]

THE MAIN effort in propulsion devices for guided missiles has centered in ramjets and rockets. With present rocket design the flight velocity should be around 3500 mph for maximum efficiency. The advantages of rockets lie in their great speed and ability to operate at extreme altitude independent of outside oxygen supply. The fuel consumption of rocket motors is very high and the pay load is low. They are very inefficient at low speeds. In an effort to reduce fuel consumption much consideration is being given to the ramjet. It will probably operate around 2000 mph with a specific fuel consumption about one sixth of that of the rocket. Its pay load is higher because it operates on atmospheric oxygen but for this reason it is limited to altitudes of 10 or 12 miles. The ramjet also requires auxiliary launching devices because it must attain speeds in the neighborhood of 700 mph before it will begin to operate.



THE COMMAND-GUIDANCE SYSTEM USES TWO RADARS; ONE TRACKS THE TARGET WHILE THE OTHER TRACKS THE MISSILE WHICH IS STEERED BY DATA FROM THE COMPUTER



THE BEAM-RIDER SYSTEM EMPLOYS A RADAR TO TRACK THE TARGET AND CONTROL EQUIPMENT IN THE MISSILE WHICH GUIDES IT ALONG THE RADAR BEAM TO ITS GOAL

The accelerations of supersonic missiles are beyond the capacity of man and automatic control is required. The simplest method of control is the preset type which employs gyroscopes to actuate flight controls. There is no control after launching and the accuracy depends on the precision of the gyro. Present accuracy is approximately four per cent of range.

Remote human control of air-to-ground missiles is being employed in several ways. One method is visual control but is limited to daytime use under good visibility. The range may be extended with television. Automatic homing to targets which emit heat, light, or radio waves is possible but limited in accuracy by the element of human judgment in

[1] Abstract of an article by Lieut. Col. William L. Clay, Liaison Officer, Ordnance Department, U. S. Army, published in *Ordnance*, November–December, 1947, pp 154–156.

target selection. The final step in this system is to use automatic radar control in place of television.

Three systems of long-range control are being developed. The "Command Guidance System" employs two radars—one tracks the target and the other tracks the missile, both feed data to a computer, and the computer transmits steering orders to the missile. The "beam-rider system" employs a radar set to track the target and control equipment in the missile guides it along the radar beam. A homing device would probably be included in the missile to control the end of the flight. These systems require microwave radar sets which operate on optical line of sight and are limited in the horizontal range over which control can be exercised. Radio navigational systems employing long wave lengths in order to send signals around the curvature of the earth are limited in accuracy. The use of celestial navigation may perhaps be the most practical solution to the problem of long-range control.

C. W. Jr.

Navy Plans Rocket Tests

THE Navy has admitted that it definitely plans further rocket tests at sea, but no firing schedule has been made, and it declined to reveal the nature of the rockets to be used in future tests.

Vice Admiral Forrest P. Sherman, Deputy CNO for Operations, an eye-witness to the firing of a V-2 from the deck of the USS *Midway*, said that the Navy obtained "a great deal of valuable information" from this initial test, despite the erratic performance of the giant missile.

He disagreed emphatically with unidentified Army ordnance experts, who have been quoted as saying that guided missiles, such as the V-2, cannot be fired accurately at sea because of the pitch and roll of ships.

Data collected from the V-2 test already are under careful study, but Admiral Sherman was of the opinion that "lots more" is needed before work will be resumed on the battleship USS *Kentucky* and the battlecruiser USS *Hawaii*, both of which are new guided-missile vessels.

Ordnance, Jan.–Feb., 1948

Dr. Martinuzzi Addresses New York Meeting

THE joint meeting of the American Rocket Society and the Metropolitan Section of the ASME on April 9 was addressed by Francis Martinuzzi of the Italian National Research Council. Dr. Martinuzzi is in charge of co-ordinating research on gas turbines, and was in Switzerland between 1938 and 1946. He is now making an extensive visit to the United States. The subject of his lecture was "Swiss Gas Turbine Development." The meeting was held in Room 501 of the Engineering Societies Building, New York, N. Y., April 9, 1948.

THE MASS-RATIO PROBLEM

ATOMIC energy will not make as much difference to rockets as it will to other forms of transportation. As far as we are able to foresee at present, this energy will always have to be taken in the form of heat, and converted to useful work in a heat engine using some working fluid such as steam. A pound of atomic fuel may give as much heat as several thousand tons of coal, enabling a warship to remain at sea for years without refueling. But it will not reduce the requirements of steam and condensing water, as compared to present ships burning coal or oil.

The rocket differs from other forms of transportation in that its working fluid cannot be saved or replaced, like the steam in a steamship, or the air in a jet-propelled plane. The working fluid must be ejected at the highest possible velocity and once ejected cannot be recaptured. Nor can it be replaced when the rocket is out in space beyond the air. That fact is inherent in the way a rocket works.

The mass ratio of a rocket is the ratio between its mass before starting and the mass it still has left when all its fuel has been burned and all its velocity changes made. If velocity change takes place in several increments the mass ratio for each increment may be computed separately, and then these separate mass ratios are *multiplied* together to give the mass ratio for the whole journey.

The mass-ratio equation is derived from the simple equation for the conservation of momentum which for the purpose may be written as follows

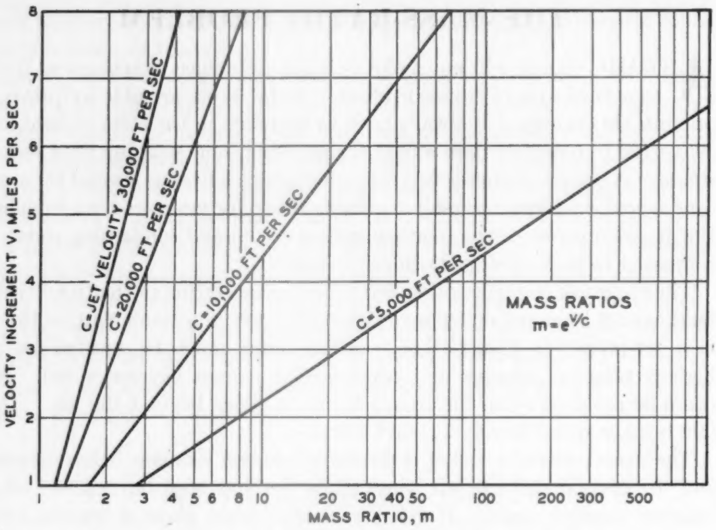
$$M\,dv = c\,dm$$

in which c is the jet velocity of the gases leaving the nozzle of the rocket; dm is a small mass of this gas; M is the mass of the rocket at the instant this small mass leaves; and dv is the small increment of velocity produced by the reaction of its leaving. It corresponds to the kick of a gun when the bullet leaves, but in the rocket the kick is the thing in which we are interested.

When this equation is integrated between the limits M_1 and M_2 the result is

$$m = \frac{M_1}{M_2} = e^{v/c}$$

in which v is the velocity increment; c is the jet velocity; and e is the base of Napierian logarithms, 2.71828. The jet velocity is calculated the same as for any nozzle, and is limited in the same way by the temperature drop, the expansion ratio, and the enormous specific volumes of gases expanded to very low pressures. Atomic energy has little effect on these limitations, except as it permits the use of working fluids such as hydrogen which have very large specific heats.



EFFECT OF VELOCITY INCREMENT AND JET VELOCITY ON MASS RATIO

The accompanying chart shows how the mass ratio is affected by various values of v and c. Velocity increments are given in miles per second, up to seven miles per second which is the velocity of escape for the earth. Various values of c in feet per second are given by the slanting lines. Intermediate values may be found by proportion. Thus the 15,000 line is twice as far from the margin as the 30,000 line. The chart is plotted on semilog paper, which for this equation puts the mass ratio on the exponential scale, while the velocity scales are linear and the curves are straight lines.

This chart shows plainly what has to be done to bring space rockets down to manageable size. A rough idea of the difficulties may be obtained by assuming hydrogen to be the working fluid, with a constant specific heat of 3.5 and a temperature drop in adiabatic expansion of 4000 F. Then the jet velocity is

$$c = 223.7\sqrt{3.5 \times 4000} = 26{,}430$$

Velocities so far obtained experimentally in rockets are generally less than 10,000 feet per second. These were attained with oxygen and hydrogen, using an excess of hydrogen to keep the temperature down. For the same jet velocity water vapor would have to have about seven times the temperature drop required by hydrogen, and carbon dioxide more than ten times as much.

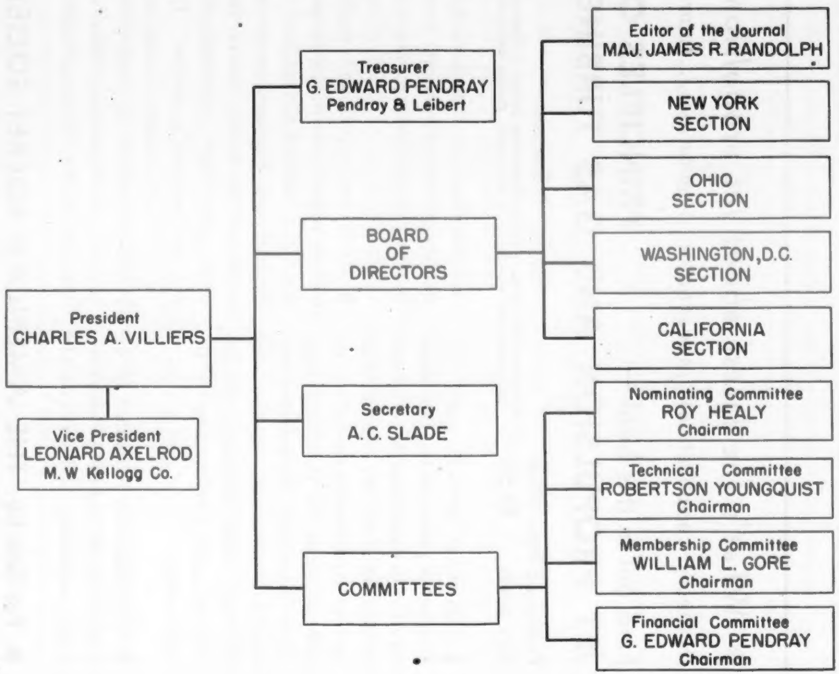
J. R. R.

Industry Armed the Nation

DURING the war American capital and labor not only armed the Nation but produced and transported to our allies 46 billion dollars of munitions, enough equipment to outfit 2000 infantry divisions, 588 armored divisions, and six air forces as large as our own largest air force, which was the Ninth. Since the war, American capitol, labor, and business have exported \$3,4000,000,000 of food, \$4,500,000,000 of machinery, and \$2,300,000,000 of textiles in addition to billions of dollars' worth of other goods.

All of this was done by a nation functioning under the supposedly weak form of government, democracy, and under that supposedly inefficient economic system, capitalism. *Ordnance*, Jan.–Feb. 1948

AMERICAN ROCKET SOCIETY ORGANIZATION CHART



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ARS BUSINESS MEETING

The Annual Business Meeting of the American Rocket Society was held in the Engineering Societies Building on December 19, 1947. There were approximately 75 members and guests present.

In the absence of Leonard Axelrod, secretary, and Cedric Giles, treasurer, Roy Healy, president ARS, after opening the meeting, gave the reports of these two officers.

The secretary reported as follows:

The developments in the American Rocket Society during the fiscal year, July 1, 1946 to June 30, 1947, indicate clearly that the Society is continuing to strengthen its position as one of the major engineering groups in the country.

Actual developments during the past year have been as follows:

1. Adoption by the membership of a new set of By-Laws of the American Rocket Society. These By-Laws call for a stronger government of the Society as a whole, a larger Board of Directors, and the formation of sections of the American Rocket Society throughout the country. The adoption of this set of By-Laws was a definite step in the program for strengthening the national scope of the organization.

2. The establishment of Sections. Preliminary work has been done during this year toward the establishment of four definite sections of the American Rocket Society. These are as follows:

   New York Section, including metropolitan New York and its suburbs.

   Washington, D. C., Section, including Washington, D. C., Virginia, West Virginia, Maryland, Delaware, and North Carolina.

   Ohio Section, including the entire State of Ohio.

   California Section, including the entire State of California.

The By-Laws controlling the development of these Sections will be placed in the hands of section organizers within a few weeks and local meetings will soon be planned. The New York Section has already elected its officers for the coming year and will present its first program in March.

3. The program for carrying advertising in the JOURNAL was put into action and as a result of a small mail campaign, ten advertisements have been contracted for during the coming year. This program is one of the most important developments in the Society this year, since the increased cost of producing the JOURNAL makes it imperative that it produce a considerable amount of income.

4. The Society during the year has established an emblem which has been developed in two forms:

   Pins: A small attractive pin has been selected for members of the American Rocket Society. Actual sales did not occur during the period covered by this report, but there is every indication that the pins will be most popular.

   Banner: A banner for the American Rocket Society has been ordered. This banner will be 4 feet × 6 feet, with a Columbia Blue background and the rocket in gray and red. The American Rocket Society will be in red lettering under the rocket. This banner has been needed for some time and will be especially useful at the 2nd Annual Convention of the Society scheduled for December, 1947.

5. The Second Annual Convention of the American Rocket Society held in conjunction with the ASME took place in Atlantic City, N. J., the first week in December, 1947. While the attendance was approximately half of that registered in New York the previous year, due without doubt to the location of the meeting, both the ASME and the American Rocket Society felt that the Convention was a success. The American Rocket Society presented Dan Kimball, executive vice-president of Aerojet Engineering Corporation, and vice-president of General Tire and Rubber Company, as the main speaker

at the Annual Dinner. Col. Marvin Demler, chief of the Flight Propulsion Branch of Army Air Forces, spoke at the luncheon. Various jet-propulsion exhibits attracted much attention.

At the Annual Dinner William L. Gore, Washington representative of Aerojet Engineering Corporation, acting as toastmaster, announced on behalf of the Board of Directors of the American Rocket Society, the following awards to be presented at the Annual Dinner in 1948:

The Robert H. Goddard Memorial Lecture: The lecturer will be selected by a vote of the membership from a list of notable persons in the field of jet propulsion prepared by the Awards Committee. Before presentation of the lecture, the awardee will be presented with a medal, a certificate, and a cash award to be determined by the Awards Committee. Selection of nominees and balloting shall be completed by March 1 of each year and the lecturer-elect notified.

The C. N. Hickman Award: This award shall consist of a medal, a certificate, and a cash award of $100, and shall be given for outstanding accomplishment in the field of jet propulsion to a member of the Society selected by the Awards Committee.

The American Rocket Society Junior Award: This award shall consist of a medal, a certificate and a cash award, and shall be given for the best paper submitted to the Society in the current year. Selection of the paper will be made by the Awards Committee.

The mechanics of these awards will be handled by an Awards Committee which shall consist of a chairman, elected by the Board of Directors, the President of the Society, the first Past-President of the Society, and two other members elected by these three and approved by the Board of Directors.

The establishment of these awards as a permanent part of the work of the American Rocket Society will do much to stimulate not only the interest of those participating in the awards themselves, but also interest all persons working in the field of jet propulsion.

Membership in the American Rocket Society continues to grow as indicated by the following figures for the years 1945, 1946, and 1947. These figures are for the year ending June 30, 1947. An ever greater increase is indicated by a preliminary check of later figures.

	1945	1946	1947	Per cent increase 1947 over 1946
Active	51	107	220	105
Associate	221	328	492	50
Junior	46	72	100	39
Total	318	507	812	60
Subscribers	60	78	154	97

The increase in active membership in the Society is particularly gratifying and all indications are that this group will continue to increase in number. However, under the new By-Laws the junior membership, now known as a student membership, is opened to a much larger group and an increase in student memberships next year must be expected.

Student members of any engineering organization are important adjuncts to its future growth, and stimulation of their interest is essential to the proper development of such an organization. However, each student member is a financial drag on the organization and future plans of the Society must include some means of counteracting the financial loss on student memberships.

The income of the American Rocket Society is derived from four sources at the present time: (1) Dues; (2) sale of books (not Goddard); (3) sales of publications; (4) sale of Goddard books. This income for the fiscal year ending June 30, 1947, has been as follows:

Dues	$3513.00
Books (not Goddard)	475.50
Publications	1525.42
Goddard Book	1665.89
Total	$7179.81

Report of the Treasurer of the American Rocket Society

Fiscal Year July 1, 1946–June 30, 1947

Cash and Income

Balance in bank, July 1, 1946	$ 74.40
Total income for year	7179.89
	$7254.29
Expenditures	7169.42
Balance in bank, July 1, 1947	$ 84.87
Accounts Receivable	
Goddard Invoices	100.00
Regular Invoices	200.00
Cash and Accounts Receivable	$ 384.87
Government Bonds (face value)	1300.00
CASH ASSETS, TOTAL	$1684.87
Liabilities	
Majestic Press	579.33
Engel, Judge & Miller	335.34
	$ 914.67

Assets and Liabilities

Cash Assets	
U. S. Government Bonds (face value)	$ 1300.00
Cash in bank	84.87
Goddard invoices	100.00
Regular invoices	200.00
TOTAL CASH	$ 1684.87
Salable Material	
Sets of Astronautics	9600.00
Journals 61–69	350.00
Miscellaneous publications	2400.00
Charts	350.00
Pendray book	3.50
Zim book	24.00
Sawyer (Gas Turbine)	48.00
Sawyer (Applied Atomic Power)	24.00
Murphy book	10.00
Smith book	15.00
Oberth book	14.00
Sanger book	10.00
Bibliography	9.00
Goddard Books	3560.50
Office Equipment	300.00
TOTAL ASSETS	$18,402.87
Liabilities	
Majestic Press	$ 579.33
Engel, Judge & Miller	335.34
TOTAL LIABILITIES	$ 914.67

Election of Officers

The results of the mail ballot for directors and officers for the ensuing year resulted in the following members being elected: President, Charles A. Villiers; Vice-President, Leonard Axelrod.

The following were elected to the Board of Directors: For term of one year: G. Edward Pendray, Lovell Lawrence, and William Gore; for term of two years: Roy Healy, H. J. R. Grosch, and Robertson Youngquist; for a term of three years: Harry Burdett, Jr., Robert C. Truax, and Edward F. Chandler.

Mr. Healy, after introducing the new officers to the members present, expressed his belief in an active successful year for the Society and said he was confident that the members would co-operate with the new Board and new officers in every way possible.

The Journal

Beginning with this issue the JOURNAL OF THE AMERICAN ROCKET SOCIETY is being printed by the Mack Printing Company of Easton, Pa., which for years has been the publisher of *Mechanical Engineering* and other prominent technical publications. Members of the ASME staff of *Mechanical Engineering* are doing much of the work.

The editor is Major James R. Randolph, who served in the Ordnance Department during the recent war, and is now a member of the faculty of Pratt Institute in Brooklyn. Major Randolph has published several noteworthy articles on rockets in the past, and has made a number of contributions to the JOURNAL. He was the speaker at the September meeting of the American Rocket Society, and has made several other speeches in the New York area, arousing interest in rockets. He is being assisted by Charles Weber, Jr., Bernard Fishman, and Colman Zola.

The March issue of the ARS JOURNAL is a month late because of delays encountered in setting up new editorial facilities and deciding on new procedures. The staff is confident, however, that the June issue will be on time.

ARS Engineering News

Automatic Flight

ON September 20, 1947, the All Weather Flying Center's automatic C-54D aircraft left Clinton County Army Air Field, Wilmington, Ohio, for Stephenville, Newfoundland. From take-off point at Stephenville, Newfoundland, the automatic C-54D completed a fully automatic transatlantic crossing to Brize Norton, England. Brize Norton is approximately forty miles due west of London.

On October 7, 1947, the automatic C-54 departed Lyneham, England, for the return transatlantic crossing to Stephenville, Newfoundland. On October 8 the automatic C-54 departed Stephenville, Newfoundland, and arrived at its home base, Clinton County Army Air Field, Wilmington, Ohio. Distances flown on the automatic flights totaled approximately 7780 statute miles.

The automatic airplane flew the North Atlantic route on the transatlantic crossings and maintained a predetermined barometric altitude of 9000 ft. A fuel supply of approximately 3700 gallons on each crossing was carried.

One button on the control panel, a button marked "Brize Norton, England," was pushed. This was the only manual operation during the entire flight. The automatic flight was carried out in twelve sequences by a self-contained electronics mechanism, the master sequence selector, without the aid of any human guidance such as a pilot on the ground or "mother" ship. No outside force directed the automatic C-54D. No human hand inside touched the controls.

The twelve sequences of the automatic flight are : (1) Pretake-off (manual alignment of the aircraft with the runway); (2) take-off; (3) initial climb (landing gear retracted automatically when the aircraft reaches 50 ft altitude); (4) climb to cruise altitude (flaps retracted automatically at 1000-ft altitude); (5), (6), (7), (8) navigation sequences (aircraft flies a ground course based on directional information from radio stations, magnetic lines of force of the earth, and air-miles computor); (9) descent to approach altitude over a preselected radio station; (10) approach on localizer directional beam; (11) final approach and descent on localizer directional beam and glide-path beam, and (12) landing.

The entire flight, from take-off to landing was automatic. All flight data were preset on the special control-panel instruments of the electronic "brain," the master sequence selector. Preset flight data included cruising altitude, cruise heading, mileage to destination, cruising speed, rate of climb, and descent. The master sequence selector is located in the main cabin and is powered by an auxiliary gasoline generator. The navigational phase of the flight is controlled by two mileage counters and magnetic heading selectors. These instruments control the flight until the plane clicks off the preset number of miles on the predetermined heading. At the end of the first navigational sequence, the aircraft "homed" automatically to a radio station located on a ship in the mid-Atlantic. At the end of the second navigational sequence, the clicking-off of the last mile on the counter threw control to the radio compass which homed in on radio station BBC at Droitwich. Final descent was geared to the AAF Instrument Low-Approach system (localizer and glide path) at Brize Norton. (*Mechanical Engineering*, Dec., 1947.)

Engineering Progress Show Planned for May 11–16, Philadelphia, Pa.

THE Engineers' Club of Philadelphia, Junior Members, are joining with The Franklin Institute of the State of Pennsylvania in sponsoring a second Engineering Progress Show on May 11–16, 1948.

Exhibits will include many items depicting the progress in engineering. The first show held in the spring of 1947 was highly successful, having an attendance record of over 10,000, and booths sold out to exhibitors in advance of the show date.

The show will be held in Franklin Hall in The Franklin Institute of Pennsylvania. In addition to the exhibits, two nationally prominent engineers will deliver lectures in the Franklin auditorium on two evenings during the week.

Exhibitors are now contracting for group space. The debut of many engineering advancements is expected to be made at this show.

Precipitation Static

AN eight-page booklet on the reduction of precipitation static in aircraft radio has been published by Dayton Aircraft Products, Inc., Dayton, Ohio, manufacturers of shielded antenna fittings for commercial aircraft as well as for the United States Air Force.

The serious problem of precipitation static in aircraft radio has been the subject of long and intensive study and research both by the Army and Navy and by commercial airlines. Only within recent years have the causes for this static been understood and efforts made to reduce this serious handicap to radio communications.

The booklet goes into considerable detail on the causes for precipitation static and describes the methods developed by the U. S. Air Forces during the war for greatly reducing this static. The methods now used consist of metal and ceramic antenna fittings, which, in conjunction with polyethylene wire, insulate the antenna system against corona discharge. These fittings are made to be used on marker beacon, compass sense, and receiving and transmitting antenna.

The antenna system as described in this booklet also provides greater assurance against breakage under icing conditions. For those technically interested, a reproduction of a U.S.A.F. technical order covering installation of this equipment on

FREE BOOKLET ON REDUCTION OF PRECIPITATION STATIC

army planes will be enclosed in the booklet. Permission to reproduce this technical order has been granted Dayton Aircraft Products, Inc., by the United States Air Forces.

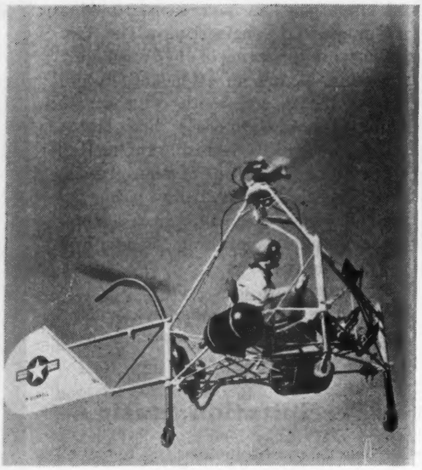
The booklet, complete with installation and maintenance instructions, may be had free of charge by writing Dayton Aircraft Products, Inc., 342 Xenia, Dayton, Ohio.

Ramjet Helicopter

THE U. S. Air Force's ramjet helicopter, said to be the first rotary-wing aircraft ever to employ this type of power plant, has successfully completed six months of flight testing at the St. Louis, Mo., plant of the McDonnell Aircraft Corporation.

Developed after almost two years of research and close co-operation between engineers of Air Matériel Command at Wright Field, Ohio, and the McDonnell Aircraft Corporation, the ramjet helicopter is actually a three-dimensional aerial motorcycle consisting only of a two-blade rotor, 18 ft in diameter, with a ramjet

RAMJET HELICOPTER



RAMJET HELICOPTER IN FLIGHT

power unit at each tip, a small rudder, and an open steel-tube structure supporting the pilot, fuel tanks, and controls. The present configuration is merely a flying test stand intended to prove the basic idea, and no aircraft designation has been given the airplane.

Although it weighs only 310 lb, the helicopter has already lifted an additional useful load of 300 lb, and has attained a forward speed of 50 mph. An important feature of the helicopter is the rotor-tip ramjet power unit, which weighs only 10 lb and is attached to the tip of each of the all-metal blades. Since power is applied directly to the blade tips, heavy engine parts, gear systems, and transmissions are eliminated, thereby greatly reducing the weight of the craft.

The ramjet power unit is simple in design, resembling a stovepipe. The whirling rotor blades will "ram" air into the duct, which is burned by a fuel mixture injected through the blade and forced out the rear of the tube, producing thrust. Since the ramjets function only at high speed, an auxiliary starter is required, the ramjets attaining proficiency when the blade tips reach a speed of 600 fps.

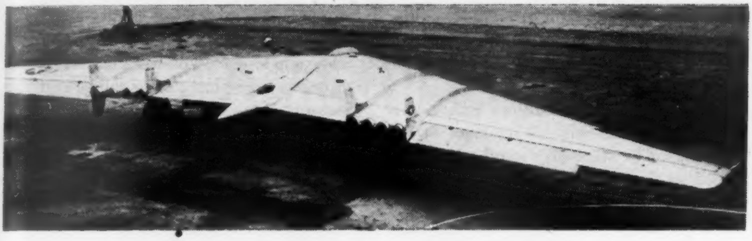
Fuel for the power plant thus far has been propane, although engineers are now working on gasoline-burning ramjets which would eliminate the necessity of carrying a special fuel supply for the helicopter into areas where the craft might be in operation. Two tanks attached to the lower fuselage supply fuel through lines into the blades. After initial fuel pressure is built up, centrifugal force provides the necessary pumping action for keeping the system in operation.

The initial flight of the ramjet helicopter was made May 5, 1947. It was made with fuel fed through a line from a supply on the ground, but subsequent flights were made with fuel carried aloft in tanks attached to the frame. (*Mechanical Engineering*, Jan., 1948.)

Eight-Jet Bomber

THE U. S. Air Force's latest jet-propelled bomber, the Northrop YB-49, a flying-wing-type aircraft, successfully completed its first test flight recently when it flew from Hawthorne, Calif., to Muroc Air Base, Calif., where it will undergo further testing.

The YB-49, a jet-propelled version of the



THE YB-49 FLYING WING JET-PROPELLED BOMBER

Northrop B-35 Flying Wing, spans 172 ft across the wing, but is only 53 ft long, due to the absence of the conventional fuselage. Instead of the four reciprocating engines on the B-35, the YB-49 is powered by eight General Electric J-35 jet engines built by the Allison Division of General Motors. The engines, arranged in groups of four on either wing, are capable of developing 32,000 hp. Service ceiling of the plane is expected to exceed 30,000 ft.

Crew capacity of the jet-propelled bomber is 13 men, including a pilot, co-pilot, navigator, radio operator, flight engineer, bombardier, and gunner, with space for six reserve crew members for relief duty on long missions.

The landing gear of the YB-49 is of the tricycle type, consisting of two main wheels, 5 ft 6 in. in diameter, and a single nose wheel, 4 ft 8 in. in diameter.

The YB-49 is controlled by "elevons," a control surface which performs the functions of both elevators and ailerons. The plane is equipped with four vertical air separators, which extend above and below the wing surface, to increase directional stability. (*Mechanical Engineering*, Dec., 1947.)

New Flexible Tubing

Titeflex, Inc., 521 Frelinghuysen Avenue, Newark, N. J., announces a new flexible tubing made with Inconel innercore and braid. The hose may be supplied for temperatures up to 1700 F. The innercore of Titeflex Inconel tubing is supplied with wall thickness of 0.005 to 0.015 in. The thicker wall tubing is recommended for the larger sizes where high pressure is the primary requisite, and the thinner wall where the pressure is not over a few hundred pounds per square inch and the weight is critical. Construction of the Titeflex tubing is such as to resist failure caused by excessive vibration. (*Mechanical Engineering*, Jan., 1948.)

Threadless Pipe Fittings

THREADLESS malleable pipe fittings, called Flagg-Flow, made for brazed pipe joints, have been introduced to industry by Stanley G. Flagg & Company, Inc., Philadelphia, Pa.

In announcing the new development, it was stated that the threadless fitting simplifies any piping layout and makes it

TITE LEX INCONEL TUBING

possible to join steel or wrought-iron pipe without threads and without welding by a brazing method any competent pipe fitter can use.

The Flagg-Flow threadless fitting is a black, malleable-iron socket-type fitting for brazing to steel or wrought iron, designed to meet the increasing demand for threadless fittings and also fittings without a chamber. The cup of this fitting is reamed to accommodate the outside diameter of standard pipe and also to produce a shoulder or stop for the pipe when it is inserted. Close tolerances in the machining of the cups insure rigid support and a thorough bond.

There is said to be materially less pressure loss due to friction and turbulence in a piping system using these fittings than in a similar system using threaded fittings. This reduced loss is particularly marked when handling viscous or semisolid fluids, and the design of the fitting reduces the effects of turbulence in the pipe and fitting. (*Mechanical Engineering*, Feb., 1948.)

Jet Fighter Airplane

THE United States Air Force's first swept-back jet fighter airplane, the North American XP-86, has successfully completed its initial test flights at Muroc Air Base, Calif.

The single-place low-wing fighter, which employs a sweepback in its wings and tail assembly, has completed approximately 30 flights and has amassed a total of about 30 hr flying time. Pilots, Air Force observers, and company engineers declared the initial flights highly satisfactory.

Designed to attain speeds in excess of 600 mph, the XP-86 is the first operational fighter with swept-back wings to fly in this country. The sweepback which delays compressibility shock waves enables the airplane to reach speeds higher than those possible with the conventional wing. Sweepback angle of the XP-86 is 35 deg for both wing and tail assembly.

Powered by a GE-Allison J-35 axial-flow jet engine capable of producing 4000 lb of thrust, the XP-86 employs the single straight ram duct, with its opening in the nose.

The XP-86 has a wing span of 37 ft, a length of 37 ft, and a height of 14 ft. It has a range of more than 1000 miles and a service ceiling of more than 40,000 ft.

The plane is equipped with a pressurized cabin and a pilot-ejection seat. The landing gear is the conventional tricycle type with a steerable nose wheel. (*Mechanical Engineering*, Jan., 1948.)

JET FIGHTER AIRPLANE WITH SWEPT-BACK WINGS